ARCHITECTURE AND URBAN DEVELOPMENT

DOI 10.15826/rjcst.2015.1.012 УДК 69.05

Perminov R. E. [1], *Noskov A. S.* [2], *Maltseva I. N.* [3], *Mattia De Rosa* [4], *Elokhov A. E.* [5]

[1–3] Ural Federal University,
Yekaterinburg, Russia
[4] University of Genoa,
Genoa, Italy
[5] Passive House Institute,
Moscow, Russia

E-mail: [1]*shaftcom@gmail.com,* [2]*referetsf@yandex.ru,* [3]*3724316@mail.ru,* [4]*mattia.derosa@unige.it,* [5]*bd@passiv-rus.ru*

PRELIMINARY ENERGY EFFICIENCY ESTIMATE OF BUILDINGS IN EXTREME CONTINENTAL CLIMATE CONDITIONS

Abstract. Construction of energy-efficient buildings becomes a top priority for many countries. Yet certain obstacles in achieving internal environment comfort standards remain in regions with extreme continental climate. In addition to engineering and economic challenges, there exist design process issues since design data should closely correspond with resulting performance of the building. This paper focuses on accurate energy demand estimation during design stage. Two types of buildings designed for Ural-Siberian region of Russia and for Kazakhstan are examined: detached and medium-rise apartment buildings. Most influential factors are taken into consideration and general recommendations on improving energy efficiency using effective combination of structural and engineering solutions are given. Adaptation of design procedure in terms of extreme continental climate made by means of simplified but precise Passive House planning tool is demonstrated.

Keywords: preliminary estimate, energy efficiency, building envelope, renewable sources of energy, extreme continental climate

Перминов Р. Э.[1], *Носков А. С.*[2], *Мальцева И. Н.*[3], *Маттиа Де Роса*[4], *Ёлохов А. Е.*[5]

[1–3] Уральский федеральный университет,
Екатеринбург, Россия
[4] Университет Генуи,
Генуя, Италия
[5] Институт пассивного дома,
Москва, Россия

E-mail: [1]*shaftcom@gmail.com,* [2]*referetsf@yandex.ru,* [3]*3724316@mail.ru,* [4]*mattia.derosa@unige.it,* [5]*bd@passiv-rus.ru*

ПРЕДВАРИТЕЛЬНАЯ ОЦЕНКА ЭНЕРГОЭФФЕКТИВНОСТИ ЗДАНИЙ В УСЛОВИЯХ РЕЗКО КОНТИНЕНТАЛЬНОГО КЛИМАТА

Аннотация. Строительство энергоэффективных зданий является приоритетным направлением для многих стран. Однако в регионах с суровым климатом часто возникают проблемы достижения нормативных показателей комфорта внутренней среды. В идеале проектные значения потребностей в электроэнергии на отопление и кондиционирование здания должны точно соответствовать итоговым показателям. В этой статье рассматриваются методики точного прогнозирования энергопотребления на стадии проектирования. Исследовано два типа зданий, проектируемых для Урало-Сибирского региона России и Казахстана: индивидуальный дом и многоквартирный дом средней этажности. Даны рекомендации по снижению энергопотребления зданий путем эффективного сочетания конструктивных и инженерных решений. Показан учет основных факторов, влияющих на энергетический баланс зданий. На примере Пакета проектирования пассивного дома 2007 приведен пример адаптации упрощенной, но достаточно точной методики расчета к резко континентальным климатическим условиям.

Ключевые слова: предварительная оценка, энергоэффективность, ограждающие конструкции, возобновляемые источники энергии, резко континентальный климат.

Introduction

It is a well-known fact that buildings are responsible for at least 40 % of primary energy consumption in EU and 45 % in Russia [1]. Inevitable depletion of non-renewable energy resources and increasing ecological awareness forces people to implement different legislative instruments at all levels of cooperation. Improving energy performance of buildings is a cost-effective way of mitigating climate change consequences and creating comfortable environment for residence. Considering great potential savings in building industry due to energy efficiency, they appear to be even greater in extreme continental climate. In recent decades a variety of approaches aimed at increasing energy performance of buildings has appeared. Choosing the most suitable approaches for climatic conditions and combining them effectively in order to achieve synergetic effect are challenging.

The aim of this paper is to study modified estimation approaches applied to predict energy consumption taking into account both internal and external environment. For this purpose, several objects located in extreme continental climate were considered, most of them being located in Yekaterinburg, Russia and representing detached houses [2], while the other objects are medium-rise apartment buildings and situated in Astana, Kazakhstan.

The benefits of predicting energy consumption are apparent as it helps to avoid additional expenses in cases when actual energy use is beyond expected levels. Furthermore, it provides accurate long-term planning and better-informed decision-making as showed by Hensen and Lamberts [3].

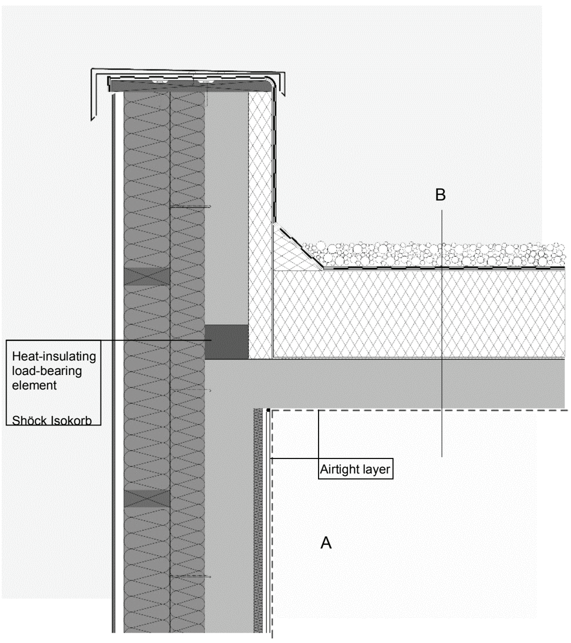
Climatic data

Territories with extreme continental climate can be characterized as isolated from World Ocean and having short summer with high temperatures followed by long winter season. Average humidity is, typically, low with rare precipitation [4]. The greatest challenge for building design is high amplitude of annual temperatures reaching the range of 65 °C and above. Therefore, one should take measures against heat loss in winter and potential overheating in summer.

Yekaterinburg and Astana were taken as an example of territories representing extreme continental climate conditions. In Yekaterinburg, for instance, average annual temperature is 2,4 °C above zero. Absolute minimum temperature is 47 °C below zero. Absolute maximum temperature is above 38 °C. Design temperature of the coldest five-day period is 32 °C below zero. The average temperature of heating period is 5,4 °C below zero, designed duration of heating season is 221 days. Total annual heating degree days (HDD) are 5614 and 6020 for Yekaterinburg and Astana respectively.

Building energy consumption calculation

Among various existing simulation and calculation methods [5, 6] the energy balance and Passive House planning tool 2007 (PHPP 2007) was chosen as the most appropriate one for reaching the abovementioned objectives. Despite major progress in simulation programs using transient equations there remain certain obstacles. Calculations of large-scale buildings are time-consuming and require high computing power. Evaluation based on building information modelling (BIM) is aimed at solving that problem but BIMs are not always introduced in design work [7, 8]. Unlike BIM-based tools, PHPP design tool is light-weighted and simplified giving only 5–10 % error in energy consumption assessment. Precision was achieved by utilizing calibration method based on computational fluid dynamics (CFD) simulations.



Section A in cm
1,5 Plaster layer
2,5 Fibre reinforced gypsum panel Rigips Rigidur H: 2 layers, 12.5 mm each
3,0 ISOVER Akustic HWP2 035
17,0 Reinforced concrete wall (reinforced with Shöck ComBar)
12,0 ISOVER Integra ZKF 1-032 - heat and sound insulation
16,0 ISOVER Kontur FSP 1-032 Easy Fix 160 -mineral wool board with glass fibre protective layer (wood 6/16 e=62.5cm,14%wp)
5,0 Rear ventilation
1,8 Exterrior cladding (larch planking, clinker)

Section B in cm
8,0 Peebles
0,4 Elastoplast membrane Bituver Monoflex
0,3 Separating layer (geotextile Adfors)
30,0 ISOVER RigiRoof 031 DAA dh, including inclination forming layer
0,3 Protective layer (geotextile Adfors)
0,03 ISOVER Metac DSB, vapour retardant for flat roofs
17,0 Reinforced concrete ceiling (reinforced with Shöck ComBar)
1,5 Plaster

Fig. 1. Flat roof detail. Perminov R., 2013.

Table 1

Thermal bridge list in PHPP 2007

Thermal bridge inputs							
Nr. of thermal bridge	Thermal Bridge Description	Group Nr.	Assigned to Group	Quantity	User Determined Length [m]	Length l [m]	Ψ [W/(mK)]
1	Along windows perimeter	15	Thermal Bridges Ambient	1	287,80	287,80	0,010
2	Detail connection of ext. wall	16	Perimeter Thermal Bridges	2	27,13	54,26	-0,044
3	Detail connection of ext. wall	17	Thermal Bridges Floor Slab	2	37,22	74,44	0,807
4	Detail connection of ext. wall	16	Perimeter Thermal Bridges	1	1,40	1,40	1,251
5	Detail connection of ext. wall	16	Perimeter Thermal Bridges	1	2,52	2,52	-0,195
6	Detail connection of ext. wall	15	Thermal Bridges Ambient	1	12,35	12,35	-0,037
7	Detail connection of ext. wall	15	Thermal Bridges Ambient	2	14,83	29,66	0,028
8	Detail connection of ext. wall	15	Thermal Bridges Ambient	40	11,00	440,00	0,021
9	Detail connection of ext. wall	15	Thermal Bridges Ambient	10	5,26	52,60	0,033
10	Detail connection of ext. wall	15	Thermal Bridges Ambient	1	5,74	5,74	0,027
11	Detail connection of ext. wall	15	Thermal Bridges Ambient	1	5,17	5,17	0,041
12	Detail connection of ext. wall	15	Thermal Bridges Ambient	2	16,22	32,44	-0,077
13	Detail connection of ext. wall	15	Thermal Bridges Ambient	6	26,63	159,78	-0,071
14	Detail connection of ext. wall	15	Thermal Bridges Ambient	1	36,40	36,40	0,014
15	Internal corner	15	Thermal Bridges Ambient	9	31,64	284,76	0,035
16	External corner	15	Thermal Bridges Ambient	5	15,47	77,35	-0,051
17	Detail connection of attic	15	Thermal Bridges Ambient	2	5,25	10,50	0,040
18	Detail connection of attic	15	Thermal Bridges Ambient	8	12,71	101,68	-0,094

Table 2

Thermal bridges in the energy balance of building in PHPP 2007

		Temperature Zone	Area	U-Value	Factor	Temp. Diff. 1	Temp. Diff. 2	P_T 1	P_T 2
Nr.	Building Element	–	[m²]	[W/(m²K)]	Always 1 (except «X»)	[K]	[K]	[W]	[W]
1.	Exterior Wall - Ambient	A	1356,6	0,113	1,00	27,7	20,8	4255	3185
2.	Exterior Wall - Ground	B	236,3	0,195	1,00	6,3	6,3	291	291
3.	Roof/Ceiling - Ambient	A	547,4	0,078	1,00	27,7	20,8	1185	887
4.	Floor Slab	B	577,3	0,278	1,00	6,3	6,3	1015	1015
8.	Windows	A	355,5	0,492	1,00	27,7	20,8	4853	3633
9.	Exterior Door	A	12,7	0,620	1,00	27,7	20,8	218	163
10.	Exterior TB (length/m)	A	1536,2	-0,001	1,00	27,7	20,8	-51	-39
11.	Perimeter TB (length/m)	P	58,2	-0,019	1,00	6,3	6,3	-7	-7
12.	Ground TB (length/m)	B	74,4	0,807	1,00	6,3	6,3	380	380
13.	House/DU Partition Wall	I	520,9	0,295	1,00	3,0	3,0	461	461
Transmission Heat Losses P_T							Total	12599	9969

Thermal envelope and thermal bridges

The main purpose of efficient design is to provide for comfort and primary energy savings. Certain strategies might be preferable according to the variety of factors such as building function and climatic conditions. Increasing insulation thickness and creating uniform thermal envelope are one of the effective strategies. In cases when creating continuous thermal layer is impossible it is recommended to apply heat-insulating load-bearing elements especially for cantilever constructions (Fig. 1).

It is important to allow for thermal bridges [9]. Document [10] introduced a concept of thermal bridge free design for energy efficient and passive houses with boundary value $\Psi \leqslant 0{,}01$ W/(m·°C) or

$$H_T = \sum_{env.surface\ j} U_j \cdot A_j + \sum_{linear\ TB\ j} \psi_j \cdot l_j + \\ + \sum_{point\ TB\ j} \chi_j \leq H_{regular} = \sum U_j \cdot A_j \qquad (1)$$

where A_j — surface area of building envelope element (m^2),

U_j — heat-transfer coefficient of building envelope element ($W/(m^2 \cdot {}^\circ C)$),

l_j — length of linear thermal bridge (m),

ψ_j — linear heat-transfer coefficient for k linear thermal bridge ($W/(m \cdot {}^\circ C)$),

χ_j — point heat-transfer coefficient for j point thermal bridge ($W/{}^\circ C$)).

Calculation methods adopted for passive houses and implemented in PHPP package enable to take into account all types of thermal bridges attributing them to respective part of the building envelope and thermal bridge groups (Table 1). Thermal bridges calculated using internal dimensions can be transformed into external dimensions via embedded tool allowing to apply both Russian and European building norms [11]. Overall fraction of heat losses from thermal bridges might reach 10 % of total transmission heat losses as shown in Tables 2 and 3.

Transparent constructions

In order to achieve comfort and low life-cycle costs, the thermal quality of transparent elements such as windows must meet stringent requirements. The requirements are directly derived from the hygiene and comfort criteria for energy efficient buildings, as well as from life-cycle cost analyses. The greatest problem in regions with cold continental climate is meeting glazing energy criterion:

$$U_{eq} = U_g - g \cdot S_{zone} \qquad (2)$$

where U_{eq} — equivalent heat transfer coefficient ($W/(m^2 \cdot K)$); U_g — glazing heat transfer coefficient ($W/(m^2 \cdot K)$), g — total solar transmittance, S_{zone} — zonal solar factor ($W/(m^2 \cdot K)$), $S_{zone} = 1{,}0 \cdot W/(m^2 \cdot K)$ for cold regions according to classification by the Passive House Institute [12].

Table 3

Transmission heat losses from thermal bridges in PHPP 2007

H-Value: $\Psi \times l$ [W/K]	Temperature Weighting Factor f_t	Weighted H-Value $f_t \times \Psi \times l$ [W/K]	Fraction of Transmission Heat Losses
2,88	1,000	2,878	0,61 %
-2,39	0,372	-0,888	-0,19 %
60,07	0,372	22,346	4,70 %
1,75	0,372	0,652	0,14 %
-0,49	0,372	-0,183	-0,04 %
-0,46	1,000	-0,457	-0,10 %
0,83	1,000	0,830	0,17 %
9,24	1,000	9,240	1,94 %
1,74	1,000	1,736	0,37 %
0,15	1,000	0,155	0,03 %
0,21	1,000	0,212	0,04 %
-2,50	1,000	-2,498	-0,53 %
-11,34	1,000	-11,344	-2,39 %
0,51	1,000	0,510	0,11 %
9,97	1,000	9,967	2,10 %
-3,94	1,000	-3,945	-0,83 %
0,42	1,000	0,420	0,09 %
-9,56	1,000	-9,558	-2,01 %

Following this criterion leads to values $U_g \leqslant 0{,}55$ $W/(m^2 \cdot K)$ which is attainable only utilizing efficient triple-glazed windows with inert gas filling and two low-emissive coatings [13]. This also means that minimum window surface temperature in most cases will deviate for maximum of 4,2 °K, guaranteeing unpleasant cold air decent absence and acceptable radiant heat deprivation. Glazing with double low-emission coating filled with 90 % argon was calculated in program Calumen II. Refer to Table 4 for the basic factors.

Table 4

Rated glazing factors obtained from Calumen II

Luminous factors (EN410-2011): (D65 2°)		
Transmittance	%	75
Outdoor reflectance	%	31
Indoor reflectance	%	32
Absorptance A1	%	12
Absorptance A2	%	2
Absorptance A3	%	5
Solar factors (EN410-2011):		
g	–	0,57
Shading coefficient	–	0,65
Thermal transmission (EN673-2011):		
U_g	$W/(m^2 \cdot K)$	0,5

Effective windows alone are not sufficient for comfortable internal environment. Potential overheating in summer due to high intensity of solar radiation requires exploiting different shading devices. Roller shutters with automatic control system, for example, allow regulating heat gain and loss in real time interacting with ventilation system.

HVAC and other engineering systems

Efficient glazing and transparent components allow to create heating system without point heat sources (e. g. radiators and convectors) drastically increasing comfort and reducing temperature stratification.

Conceptual ventilation system of energy efficient building (Fig. 2) is divided into 3 areas: first — incoming (supply) air area, which includes all living rooms; second — overflow area, which includes, for instance, passages and staircases. Third area — exhaust air area that connects all wet premises. Air velocity in ventilation slots of high-grade ventilation system is less than 1 m/s and air change rate (n_{50}) is less or equal than 0,6 1/h. Air change rate is of great value due to high potential losses through ventilation exhaust. Increasing n_{50} from 0,6 up to 2,0 might result in 43 % growth of specific space heat demand or even greater without recuperation. Air nozzles of long-range supply should be installed after sound attenuators (duct silencers) leading to a stable directed airflow from premises with supply air to premises with exhaust air passing through overflow area and additionally reducing overall air duct length [14]. High rate of heat recovery (more than 75 %) is an essential condition for energy efficient houses in cold climate.

Performance coefficient of heat exchangers might be calculated through diverse approaches. We find most explicative the following:

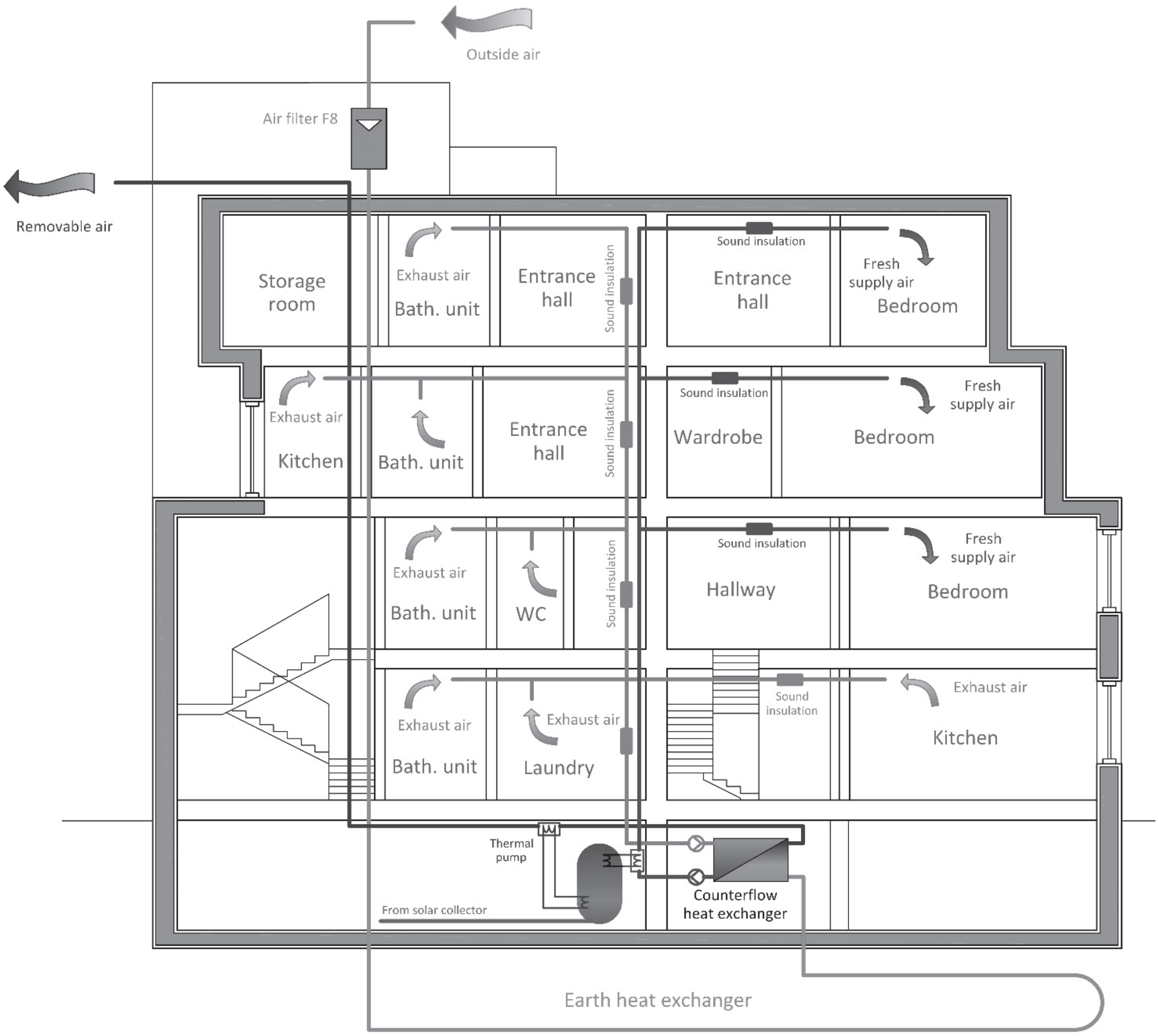


Fig. 2. Conceptual scheme of energy efficient building ventilation system. Perminov R., 2013

$$\eta_{WRG} = \frac{\vartheta_{ETA} - \vartheta_{EHA} + P_{el} / \left(\dot{m} C_p\right)}{\vartheta_{ETA} - \vartheta_{ODA}} \qquad (3)$$

where η_{WRG}— heat exchange efficiency coefficient (heat exchanger performance coefficient),

ϑ_{ETA} – temperature of extract air (°C),

ϑ_{EHA} – temperature of exhaust air (°C),

ϑ_{ODA} – temperature of outdoor (external) air (°C),

P_{el} – electrical total power consumption (W),

$\dot{m}$ – mass flow rate (kg/s),

C_p – air specific heat capacity (J/kg).

Considering low winter temperatures the design of counterflow heat exchanger should be improved. The general concept is that basic parts of the design are three heat exchanger modules performing step-by-step heating of air. Combined with ground heat exchanger, the system does not require any icing protection and is able to operate up to 35 °C below zero. Another important quality is the purity of air ducts with fine filter after air inlet (class F7 or F8). Before air is removed from building, it passes through class G3 filter. With least maintenance even after 10 years, ventilation system remains hygienic.

Benefits of renewable energy sources should be reconsidered according to climate characteristics. Basic installations are solar collectors, photovoltaic elements (PVE) and ground-coupled heat exchanger with thermal pump. Calculations of PVE were made in PVWatts calculator. Annual solar radiation for Yekaterinburg is 3,95 kWh/m2/day which means that meeting most part of hot water or heating energy demand will require big amount of PV elements and is not always reasonable [15]. Vacuum tube solar collectors cover up to 50 % of hot water demands and increasing their contribution in total energy balance of building is not cost-effective. Vacuum tubes are ca-

Table 5

Performance rating of single individual house in Yekaterinburg

Applied:	Monthly method	
Treated floor area	m^2	1695,8
Specific space heat demand	kWh/(m^2·a)	27,8
Pressurization test result	h^{-1}	0,57
Specific primary energy demand (DHW, heating, cooling, auxiliary and household electricity)	kWh/(m^2·a)	184
Specific primary energy demand (DHW, heating, and auxiliary electricity)	kWh/(m^2·a)	160
Energy conservation by solar electricity	kWh/(m^2·a)	12
Heating load	W/m^2	13
Frequency of overheating	%	0
Specific useful cooling energy demand	kWh/(m^2·a)	0
Cooling load	W/m^2	6

Table 6

Performance rating of medium-rise apartment building in Astana

Applied:	Monthly method	
Treated floor area	m^2	3761,0
Specific space heat demand	kWh/(m^2·a)	21,2
Pressurization test result	h^{-1}	0,5
Specific primary energy demand (DHW, heating, cooling, auxiliary and household electricity)	kWh/(m^2·a)	141
Specific primary energy demand (DHW, heating, and auxiliary electricity)	kWh/(m^2·a)	56
Energy conservation by solar electricity	kWh/(m^2·a)	7
Heating load	W/m^2	13
Frequency of overheating	%	0
Specific useful cooling energy demand	kWh/(m^2·a)	0
Cooling load	W/m^2	6

pable of performing at negative temperature and less affected by snow covering [16, 17].

Average wind speed and medium amount of solar radiation, not mentioning economic aspects, result in limited application of solar collectors, PV elements and wind turbines. Hence, geothermal energy should be relied on owing to the stability of energy output. Ground-coupled heat exchanger (GCHE) designed for the project of individual house (q. v. Introduction) has three loops with nonfreezing heat carrier 200-meter length each. All loops are buried into the ground for 3,0 meters deep that is below depth of frost penetration. GCHE either pre-heats and cools outdoor air when necessary or works as a ground source heat pump (GSHP) [18]. Heat pump produces additional energy using temperature differences and keeps the excess in thermal storage. Thermal storage uses water as a heat carrier and therefore can be utilized as hot-water supply and calorifer (heat exchanger) for heating system.

Resulting performance and conclusions

Overall performance ratings of individual house and medium-rise building based on PHPP 2007 are shown in Tables 5 and 6. These results reveal that various components and materials combined correctly enable to achieve significantly low specific space heat demand. Nowadays, further decreasing energy consumption is not economically reasonable in extreme continental climate conditions but is definitely possible. Performing preliminary estimation of energy efficient buildings is both challenging and important as it often defines the viability of a project. In this paper, only general recommendations were reviewed. Each building component should be further examined in detail in order to achieve more accurate estimation results. Since technology is evolving, we are confident that in the near future passive houses and even net-zero energy buildings (NZEB) will become economically rational in regions with extreme continental climate making such studies relevant.

References

1. Martynov A. S., Semikashev V. V. Problemy effektivnogo teplosnabzheniia [Problems of effective heat supply]. Available at: <http://solex-un.ru/sites/solex-un/files/energo_review/konsolidirovannyy_obzor_— problemy_effektivnogo_teplosnabzheniya —.pdf> (accessed 13.02.2015) (In Russ.).

2. Perminov R., Maltseva I., Kaganovich N., Yolohov A., Energy-efficient multi-comfort group of buildings in Svetlorechenskiy estate. *Applied Mechanics and Materials*, 2015, vols. 725–726, pp. 1389–1394.

3. Hensen J., Lamberts R. *Building performance simulation for sustainable building design and operation*. London, Spon Press, 2011.

4. Rakovskaia E. M., Davydova M. I. *Fizicheskaia geografiia Rossii* [Physical geography of Russia]. Moscow, Vlados Publ., 2001, parts 1–2. (In Russ.).

5. Nielsen T. R. Simple tool to evaluate energy demand and indoor environment in the early stages of building design. *Sol Energy*, 2005, vol. 78, no. 1, pp. 73–83.

6. Crabb J., Murdoch N., Pennman J. A simplified thermal response model. *Building Services Engineering Research & Technology*, 1987, vol. 8, pp. 13–9.

7. Motawa I., Carter K. Sustainable BIM-based evaluation of buildings. *Procedia — Social and Behavioral Sciences,* 2013, vol. 74, pp. 419–428.

8. Kim J. B., Jeong W. S., Clayton M. J., Haberl J. S., Yan W. Developing a physical BIM library for building thermal energy simulation. *Automation in Construction*, 2015, vol. 50, pp. 16–28.

9. Feist W. *Gestaltungsgrundlagen Passivhäuser* [Fundamentals of designing passive houses]. Darmstadt, Verlag Das Beispiel, 2011. (Russ ed.: Faist V. *Osnovnye polozheniia po proektirovaniiu passivnykh domov*. Moscow, ASV Publ., 2011).

10. Feist W. Wärmebrückenfreies Konstruieren [Construction without thermal bridges]. *Protokollband Nr. 16 des Arbeitskreises kostengünstige Passivhäuser.* Darmstadt, Passivhaus Institut, 1999.

11. *EN ISO 10211, Thermal bridges in building construction — Heat flows and surface temperatures — Detailed calculations*. European Committee for Standardization, 2007.

12. *Certification criteria for certified passive house glazing and transparent components*. Darmstadt, Passive House Institute, 2012.

13. Chesnokov A. G. *Svetopropuskanie okonnykh konstruktsii i razlichnye sposoby dostizheniia normativnykh rezul'tatov* [Light transmission of glazing and different methods of achieving normative results]. Moscow, GIS Publ., 2000.

14. Grondzik W., Kwok A. *Mechanical and electrical equipment for buildings*. New York, Wiley, 2014.

15. Eiker U. *Solar technologies for buildings*. Chichester, John Wiley and Sons, 2003.

16. Ochieng R. *Solar collectors and panels, theory and applications*. Sciyo, 2010.

17. Tagliafico L., Scarpa F., De Rosa M. Dynamic thermal models and CFD analysis for flat-plate thermal solar collectors — a review. *Renewable & Sustainable Energy Reviews*, 2014, vol. 30, pp. 526–537.

18. New passive house building services using heat pumps. *Protocol volume No. 26 of the research group for cost-effective passive houses phase II*. Darmstadt, 2004.